

# An Introduction to STOP Analysis- Part II

## STOP Analysis on the GLAS Project

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Karim Iman, Optical Bench

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An Introduction to STOP Analysis- Part II STOP Analysis on the GLAS Project

## Agenda

- STOP Analysis Tools
- GLAS Instrument STOP Analysis
  - Telescope
  - Optical Bench

# STOP Analysis Tools

- UAI/NASTRAN Thermal Analyzer
- FEMAP
- Thermal Model/Structural Model Comparator Program (nmgtt\*)
- Opoly Program- Coefficients of Zernike Polynomials

\* Created by: Paul Kirchman, Orbital

# NASTRAN Thermal Analyzer

- Set of temperature predicts obtained from a thermal model (Seed).
- Use the seed temperature data in conjunction with the SPC cards.
- Use APP HEAT solution sequence to obtain TEMP cards for the entire model GRID points.
  - Model should be free of RBE's, PCOMP, QUADR, TRIAR
  - MATT4 and MATT5 cards must contain material conductivity with consistent units.
- Run SOL STATICS (static solution sequence) to obtain deformations:
  - Append the obtained TEMP cards to the model.
  - Remove SPC's with seed temperature data.
  - Include SPC's to constraint model at physical interface.
  - Include MPC equations.

# UAI/NASTRAN Thermal Analyzer

```
ID IMAN,GLAS
SOL STATICS
APP HEAT
TIME 4
MEMORY = 60MW
ASSIGN PUNCH = THERM,PCH,NEW,REALLOC
CEND
$
$ LICENSE NO 96-SGI8-001
TITLE = GLAS BENCH - THERMAL DISTORSION ANALYSIS
SUBTITLE = RUN TO RECOVER THERMAL PROFILE FOR BENCH BASED ON CHARLES TEMPS
ECHO = NONE
SPC = 2
TEMP(LOAD)=1
THERMAL(PRINT,PUNCH) = ALL
BEGIN BULK
TEMPD,1,13.          ←
$                     ←
SPC,2,23,1,19.621    ←
SPC,2,25,1,20.378
SPC,2,44,1,22.063
SPC,2,45,1,22.324
```

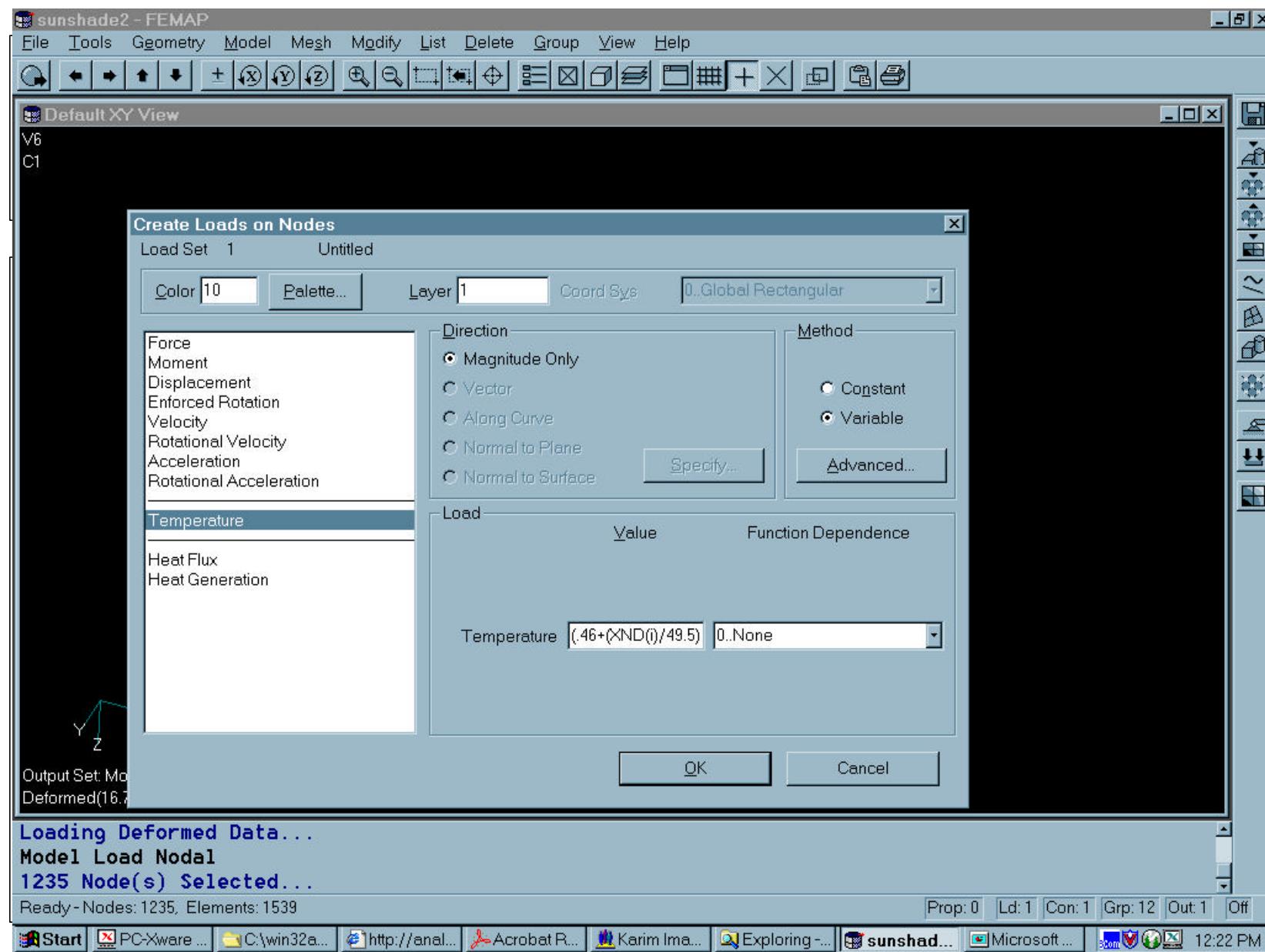
Required for thermal analyzer

Starting point for temperature interpolation

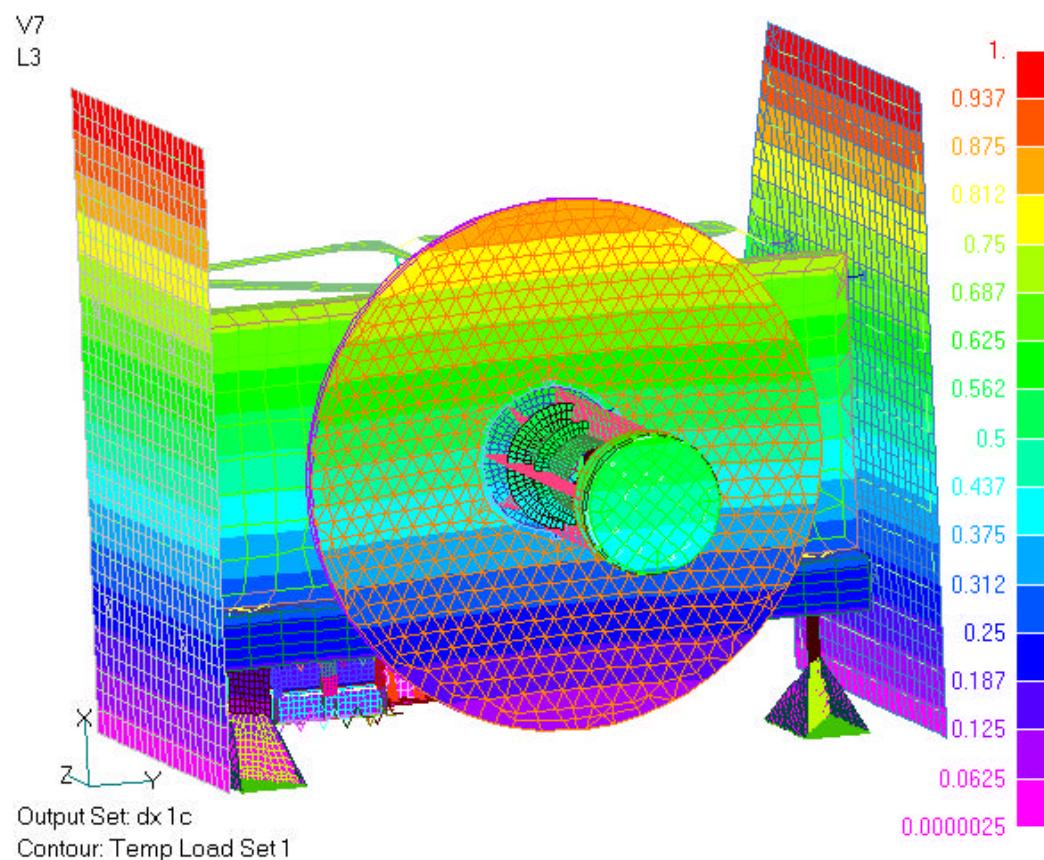
Seed Temperatures on SPC cards

# FEMAP

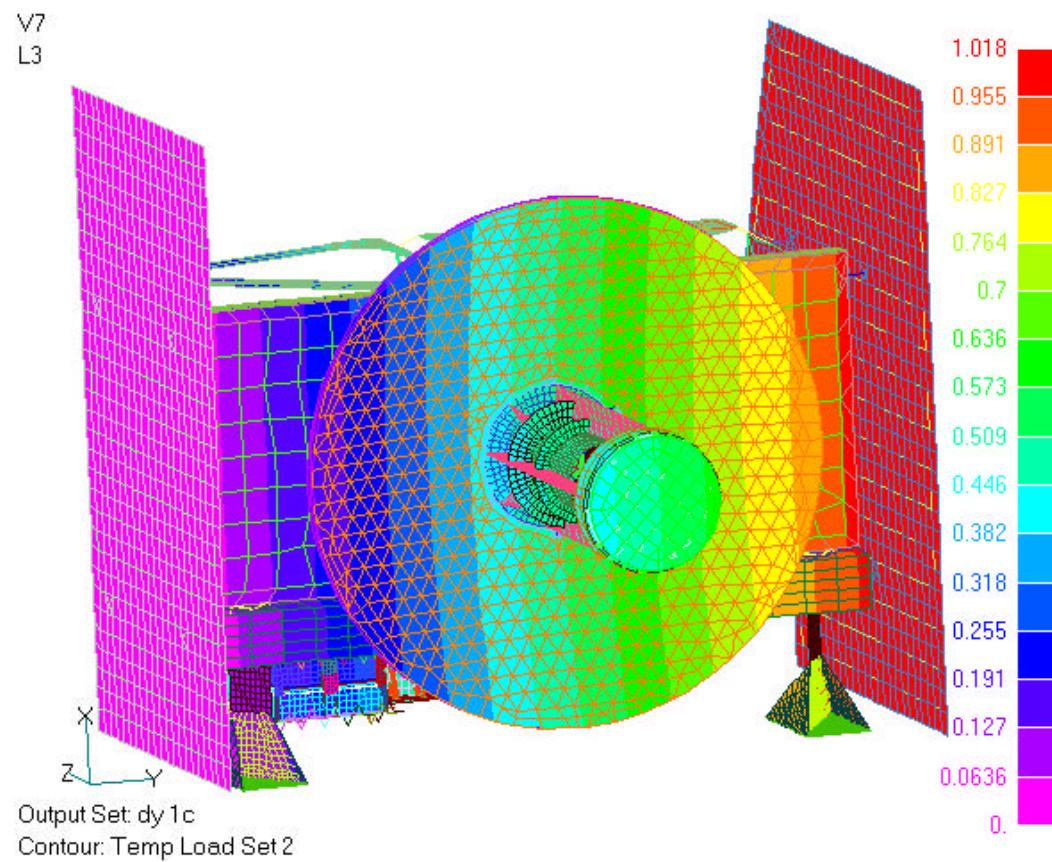
- FEMAP can be utilized to create the TEMP cards for sensitivity analysis ( i.e., thermal gradients)
- for applying a unit gradient along the X-axis of model, use the following equation X
  - Min X = -23.41”, Max X = +26.31”
  - $X_{total} = (23.41+26.31) = 49.52”$ ,  $X_{min} = 23.41/49.52 = 0.4687$
  - FEMAP Temp Value =  $0.4687 + (X_{ND}(i)/49.52)$
  - for Y and Z axes use YND(i) and ZND(i) functions, respectively.



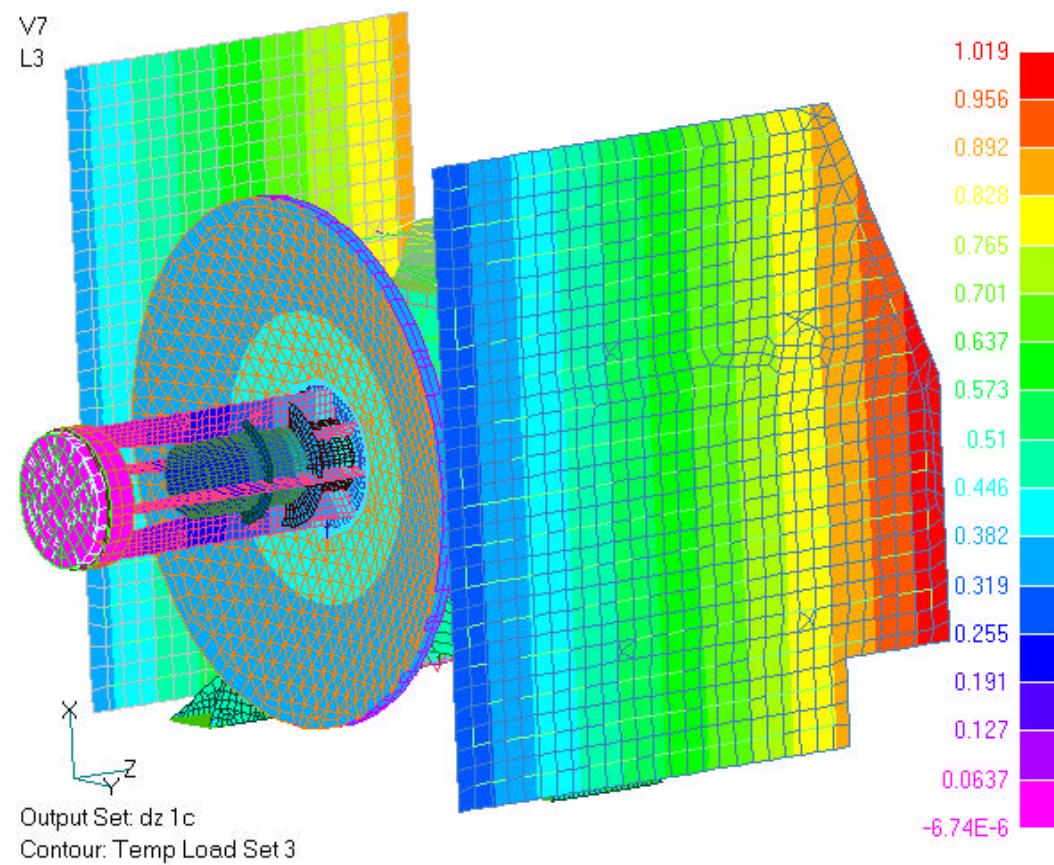
# Instrument Unit Gradient-X



# Instrument Unit Gradient-Y



# Instrument Unit Gradient-Z



# Thermal/Mechanical Model Comparator Program

- This program was developed specifically for comparing a coarse Thermal model to a relatively detail structural model to obtain the TEMP cards.
  - Both models must be in the same coordinate system.
  - Models must have consistent units.
  - Only the GRID cards in the structural model are used.
  - The thermal model data should be in a form of:
    - X,Y,Z,TEMP<sub>i</sub> (i= 1,5)
  - A tolerance value is supplied by the user for the program to determine the comparison precision.

# Thermal/Structural Model Comparator

D:>nmgtt\_nov97.exe

nmgtt command line requires two input and one output file names

nmgtt input1 input2 output

this program reads a comma delimited file of locations with temperatures in the format: id,x,y,z,t1,t2,t3, etc. where t(n) are temperature cases.

The second input must be a data file of NASTRAN grid locations in the basic coordinate system. The program will apply the nearest thermal node temperature to the NASTRAN grids and output TEMP cards.

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# MSC/Opoly

Procedure for the calculation of optical coefficients for deformed structures. The procedure works by using model geometric information to generate multi-point constraint equations to solve for the Zernike polynomial coefficients of deformed optical structures.

## **Three step process:**

Step1- Apply pressure load on the optical surface nodes for which the polynomial fit is desired.

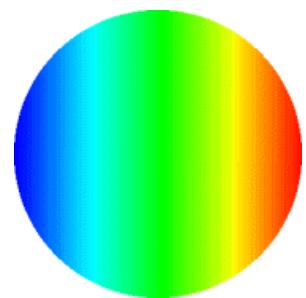
Step 2- Utilize MSC/Opoly to calculate MPC equations which will fit Zernike polynomials to the surface deformation.

Step 3- Append the equations obtained in the Step2 to NASTRAN model and run desired loading cases (i.e. thermal gradient, bulk temp change, etc.)

The 28 coefficients obtained above are fed to CODE IV or ZMAX optical programs to analyze the distorted optical surfaces.

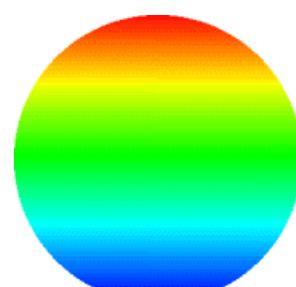
# Graphical Representation of the Zernike Polynomial 4th Degree

$r \cos\varphi$



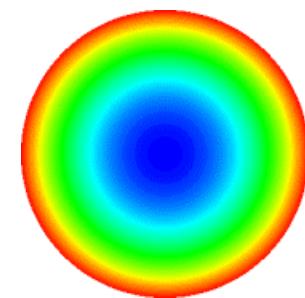
Tilt x direction

$r \sin\varphi$



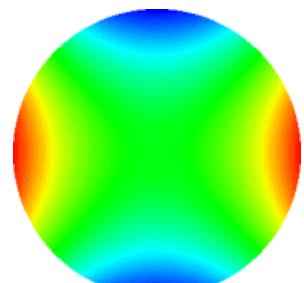
Tilt y direction

$2r^2 - 1$



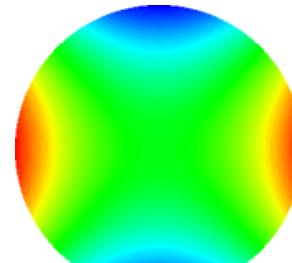
Defocus

$r^2 \cos 2\varphi$



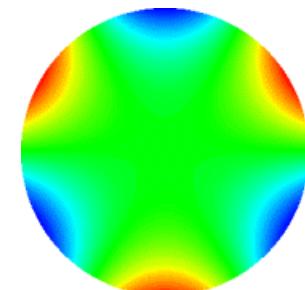
Astigmatism 1<sup>st</sup>  
order 0°

$r^2 \sin 2\varphi$



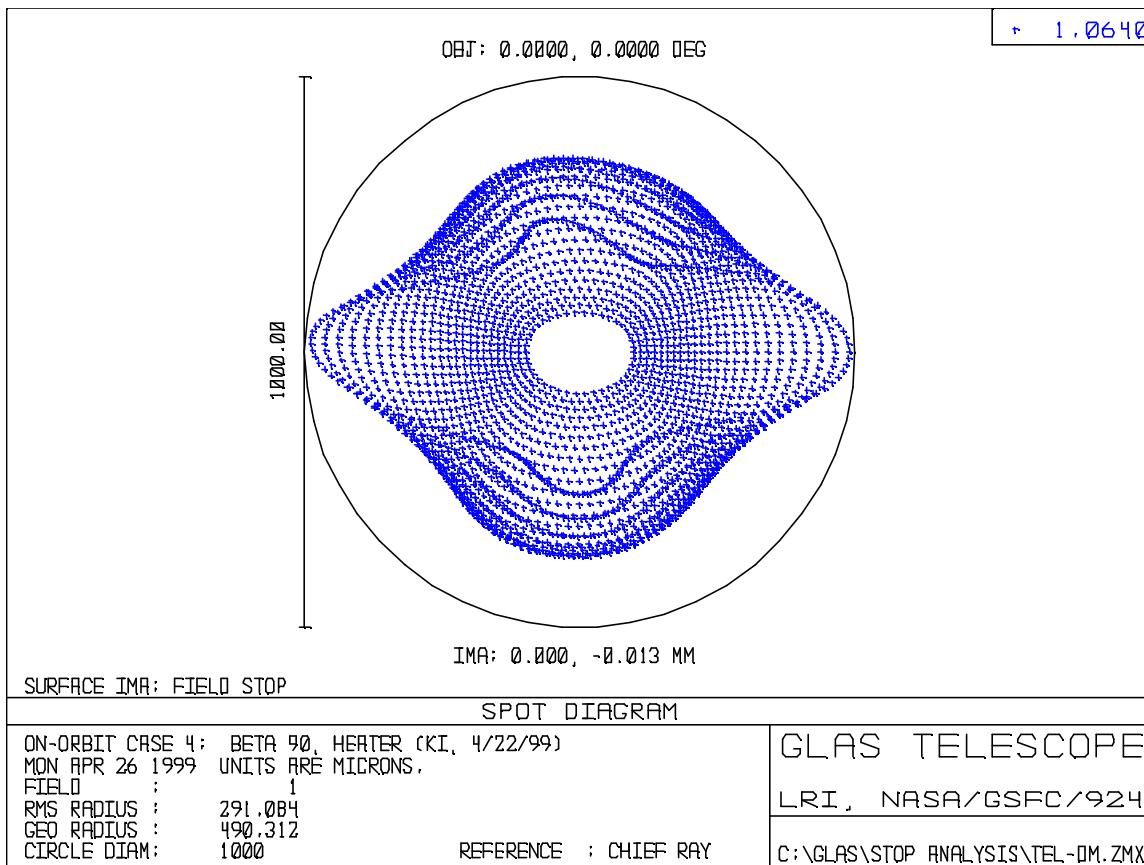
Astigmatism 1<sup>st</sup>  
order 45°

$r^3 \cos 3\varphi$

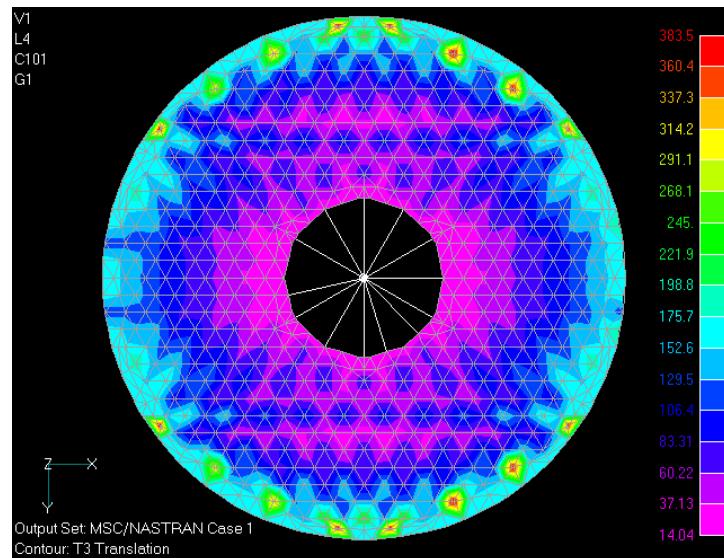
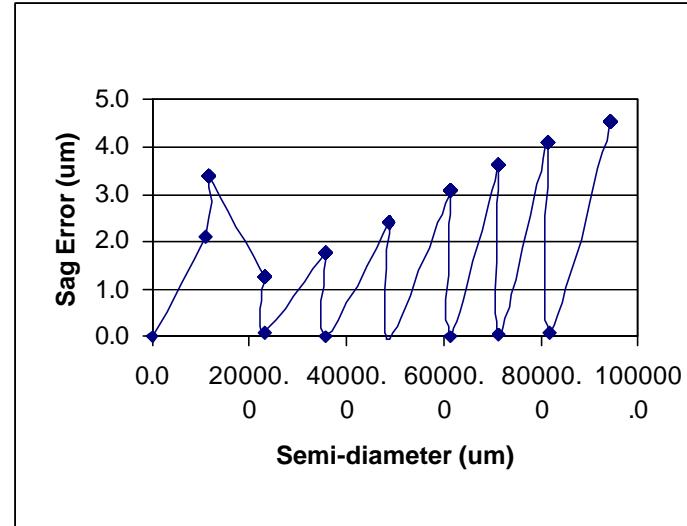
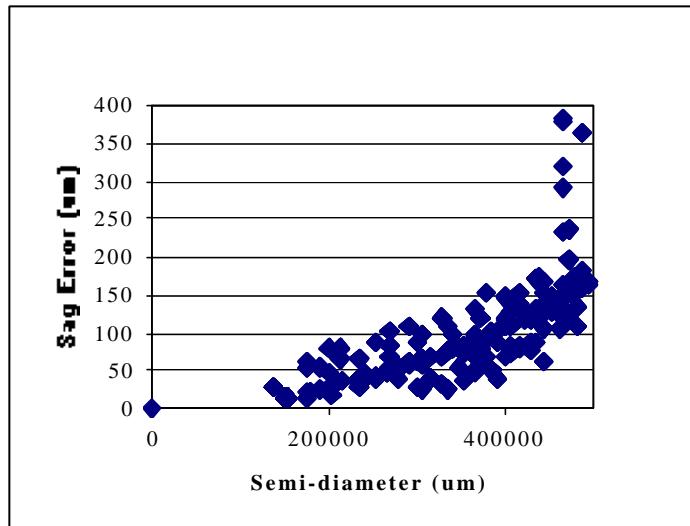


Trifoil 0°

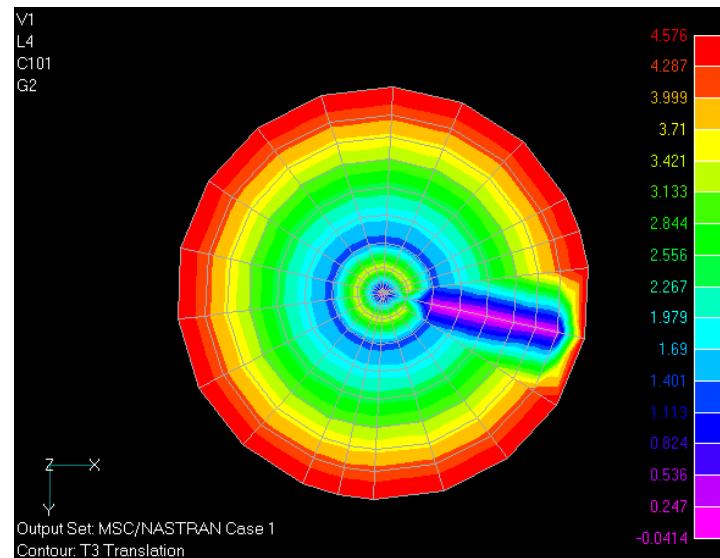
# SPOT Diagram based on Zernike Polynomial Coefficients



# GLAS Telescope FEM (uncorrected): Departure from Nominal Prescription



Primary Mirror



Secondary Mirror

# MSC/Opoly Zernike Polynomial Coefficients

- Lessons learned-
  - Finer mesh on the primary and secondary is required to maintain “flat” QUAD4’s and TRIA3’s.
  - Use double precision (wide field) GRID cards.
  - Verify that the optical surface adheres closely to the optical prescription (Optometrist Program).

# GLAS Telescope

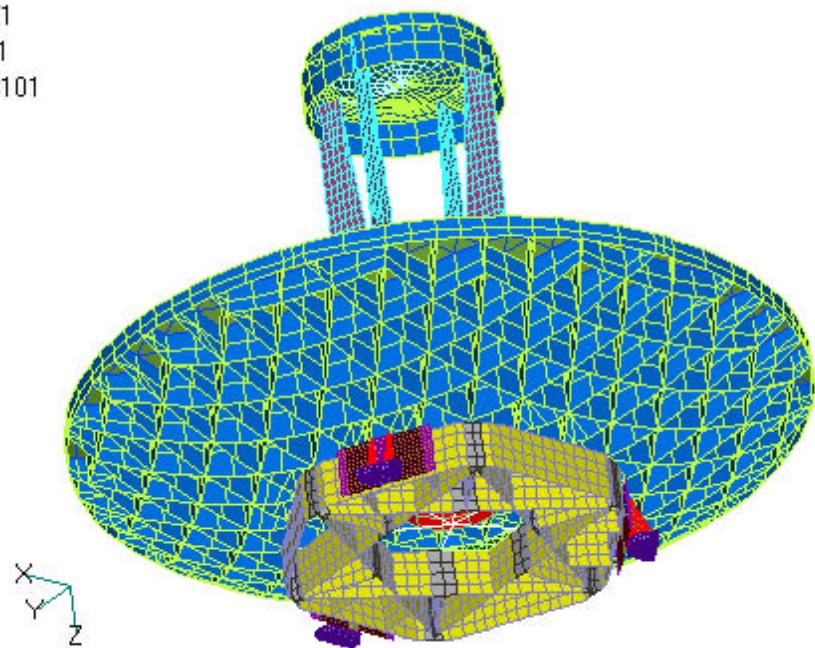
- Telescope- 1000 mm Primary and 240 mm Secondary, All Beryllium
- Finite Element Model Weight ~76 lbs. (34.5 Kg) CG at (X,Y,Z) = 0,0,-2.3"
  - Number of Nodes = 11,499
  - Number of Elements = 11,745 (CQUAD4, CTRIA3, CPENTA, CHEXA,CBAR)
- Material Properties-
  - Mirrors, tower and interface plate, Be I-220-H CTE=11.3E-6 in/in/°C, Conductivity, k=150 W/m°K
  - Plating, Nickel CTE=12.5E-6 in/in /°C, Nominal Thickness: 0.003" front, 0.001" back
  - Flexures, Ti-6AL-4V, CTE=9.5E-6 in/in /°C, k=7.3 W/m°K
  - Fasteners, A286 AMS573, CTE=11.3E-6 in/in /°C, k=12.5 W/m°K
  - Interface Brackets, CRES17-4 PH, CTE=11.5E-6 in/in /°C, k=14 W/m°K

# Telescope STOP

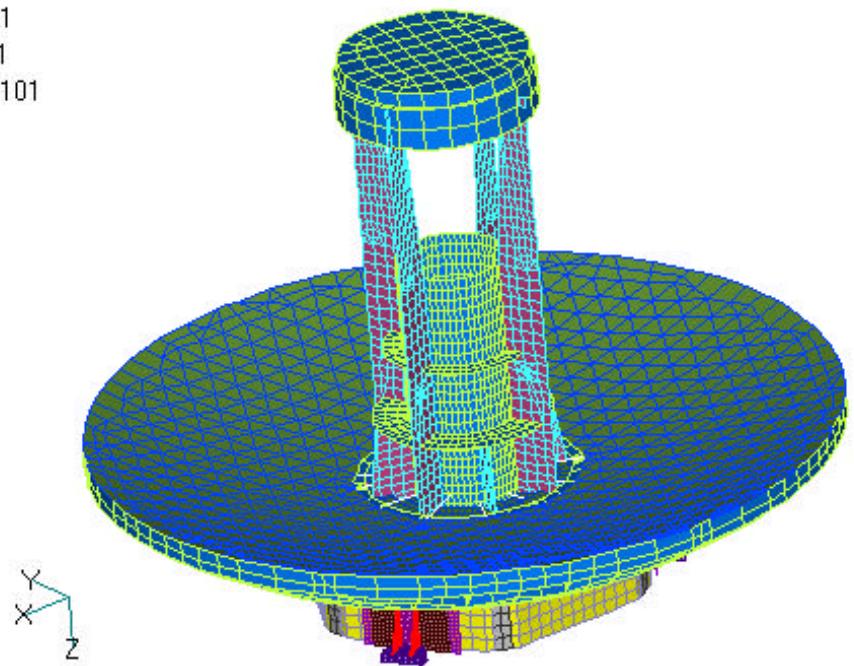
- Tilt and de-center terms on Primary/Secondary vertices
- Zernike Polynomial utilizing MSC/NASTRAN Opoly Program (Surface Deformation & Image Quality Analysis)
- MathCad curve fitting approach on the deformed/undeformed Primary/Secondary surface nodes

# GLAS Telescope

V1  
L1  
C101



V1  
L1  
C101



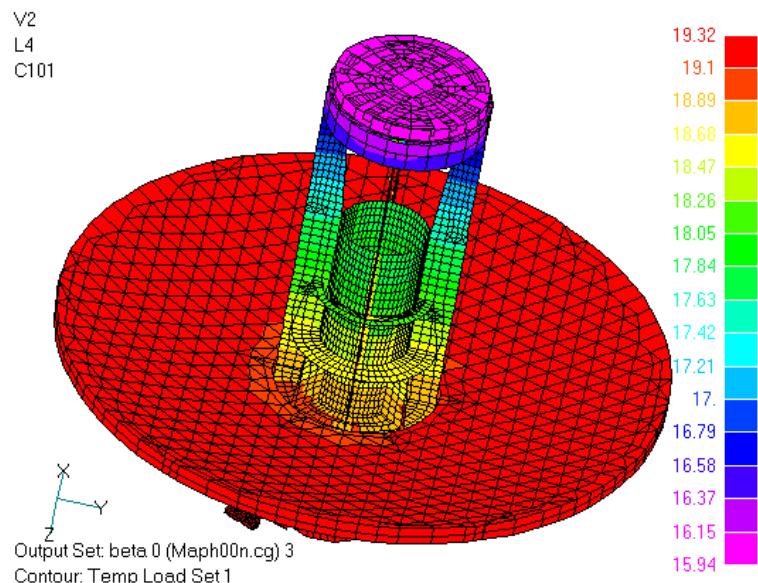
# GLAS Telescope STOP Analysis

## GLAS Telescope On-Orbit Thermal Cases (4/22/99)

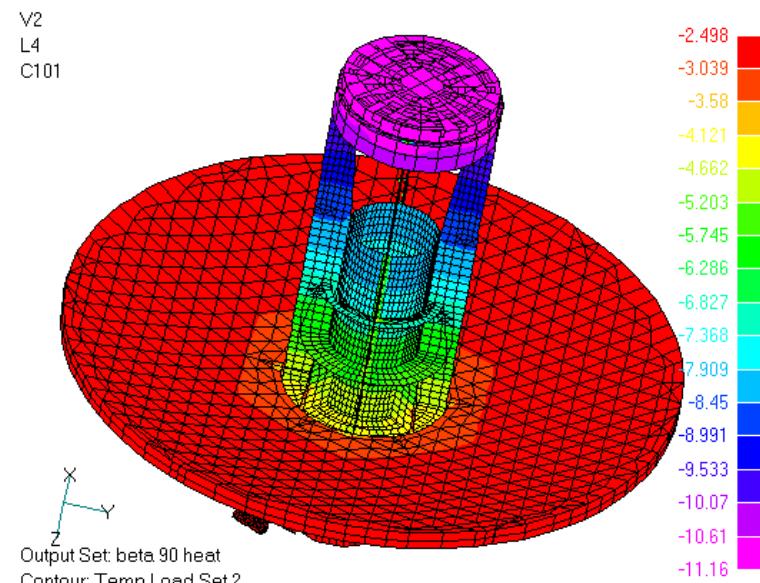
<u>CASE</u>	<u>M1</u>	<u>M2</u>	<u>M1-M2dT</u>
1. Beta 0, No Heater	19.3C	15.9C	-3.4C
2. Beta 90, With Heater	-2.5C	-11.2C	-8.7C
3. Beta 67, No Heater	18.9C	18.8C	-0.1C
4. Beat 90, No Heater	-23.7C	-26.2C	-2.5C

- No significant primary mirror radial gradients
- Secondary always colder than primary
- Axial gradient dominates telescope blur circle

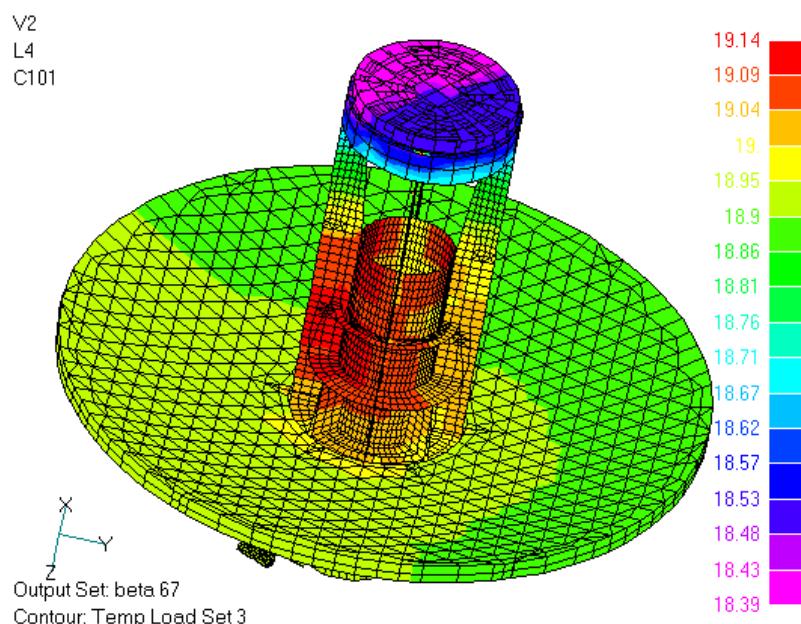
### Case 1: Beta 0, No Heater



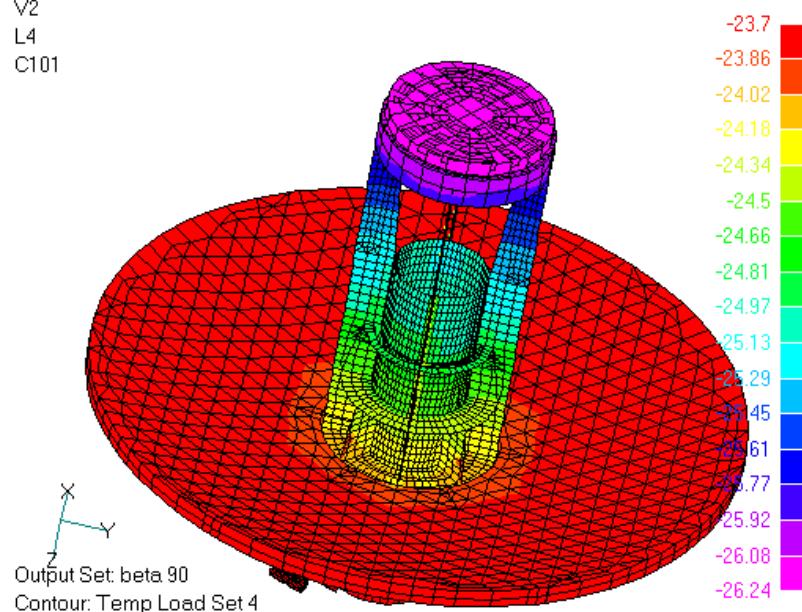
### Case 2: Beta 90, Heater



### Case 3: Beta 67, No Heater



### Case 4: Beta 90, No Heater



# NASTRAN Analysis Results

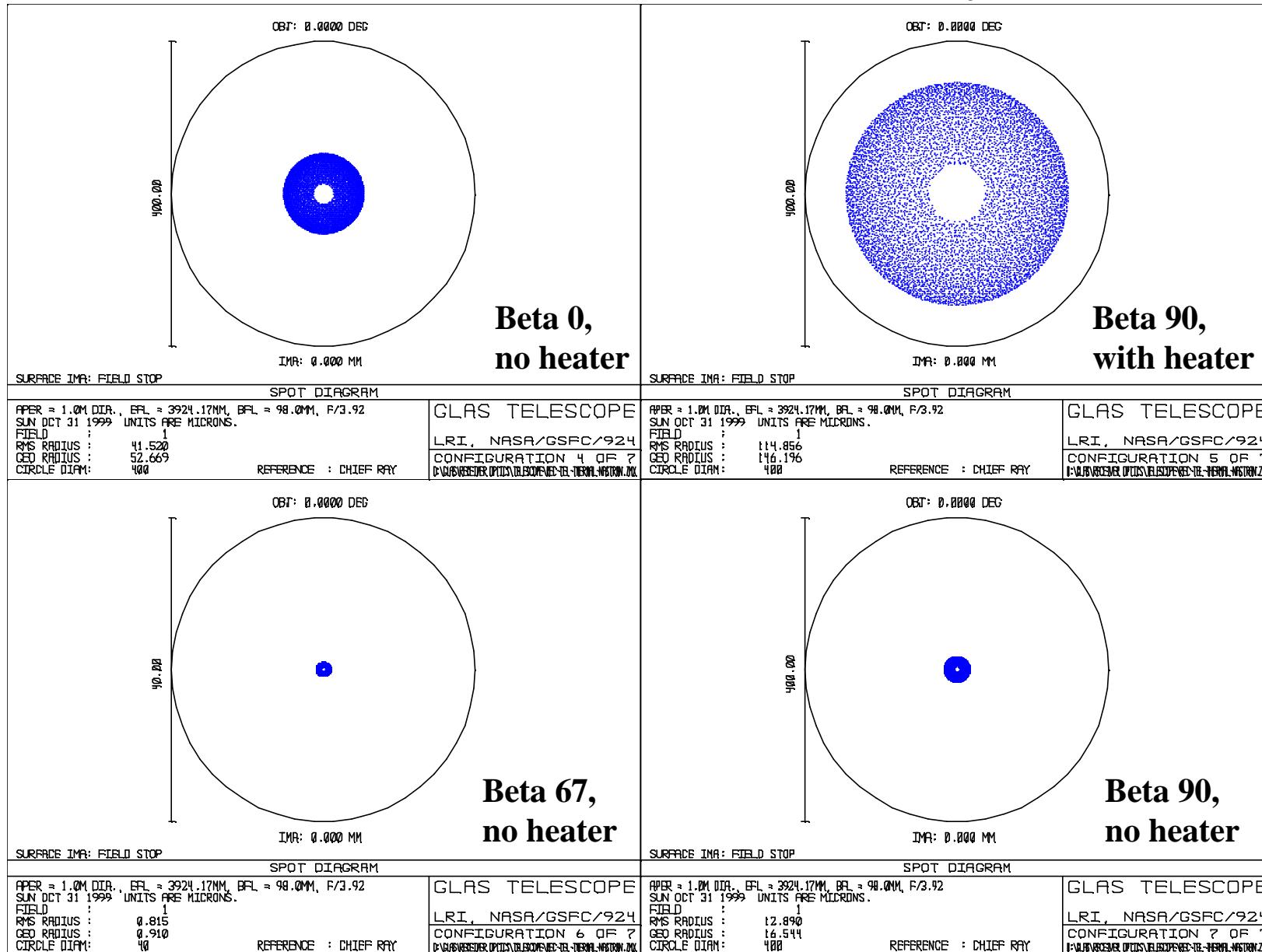
## NASTRAN-Predicted On-Orbit Telescope Prescriptions

		Case #1	Case #2	Case #3	Case #4
Component	Nominal (20C)	Beta 0, No heater	Beta 90, Heater	Beta 67, No heater	Beta 90, No Heater
M1 Radius	-1400.000	-1399.992	-1399.649	-1399.981	-1399.304
M2 Radius	-294.054	-294.035	-293.942	-294.046	-293.899
Tower V <sub>12</sub>	579.200	579.186	579.023	579.193	578.911
BFD	98.000	97.999	97.957	97.998	97.916
RMS Blur Circle	Diff. Lmtd.	18.7urad	51.7urad	Diff. Lmtd.	5.8urad

Units mm

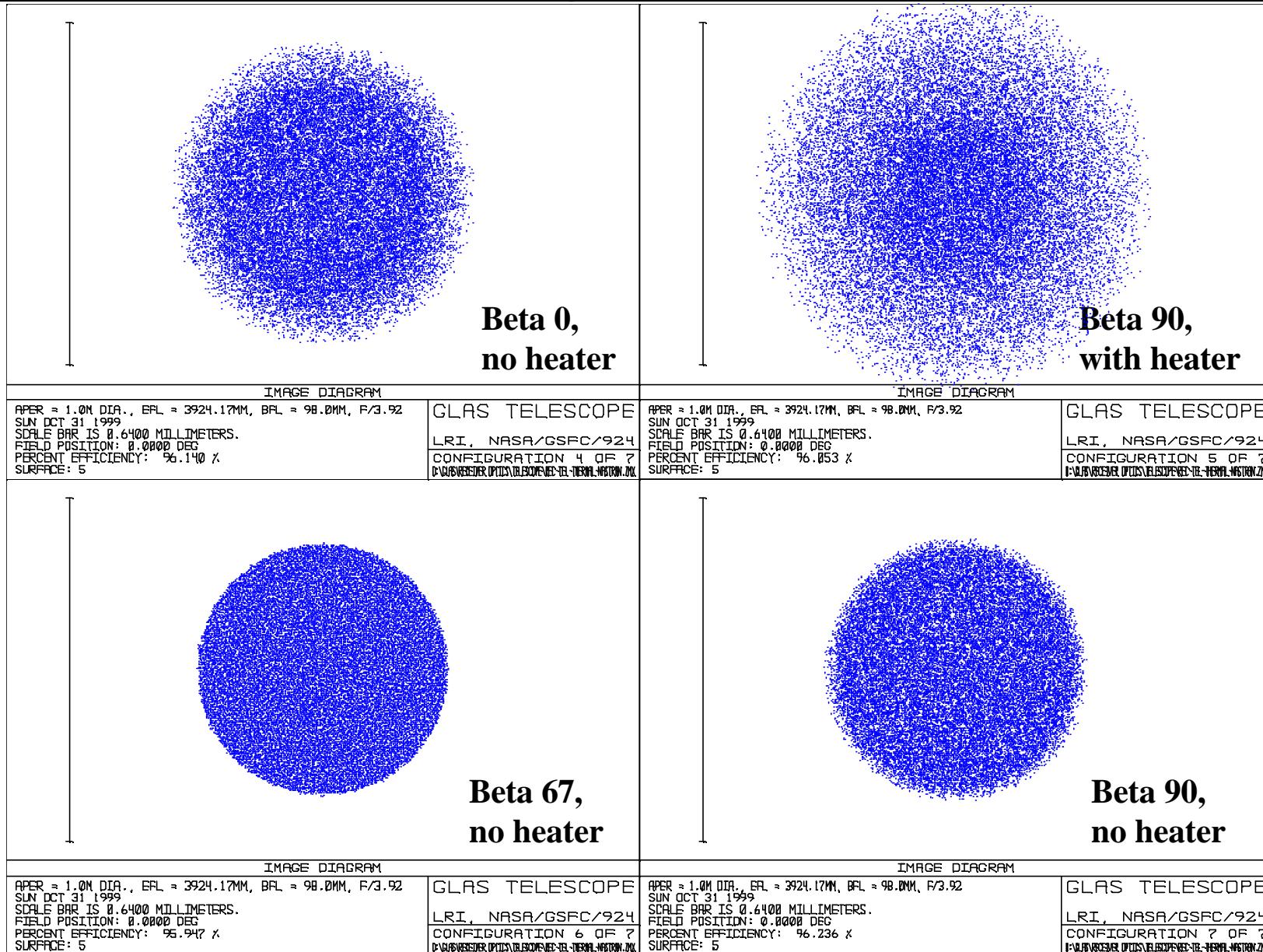
- Results agree very well with 1<sup>st</sup> Order Analysis
- Heater case has worst effect on image quality due to large (8.7C) induced telescope axial gradient

# GLAS On-Orbit Cases: NASTRAN Analysis Results



**Circle = 100urad**

# GLAS On-Orbit Cases: Images (120urad Object/160urad Det.)



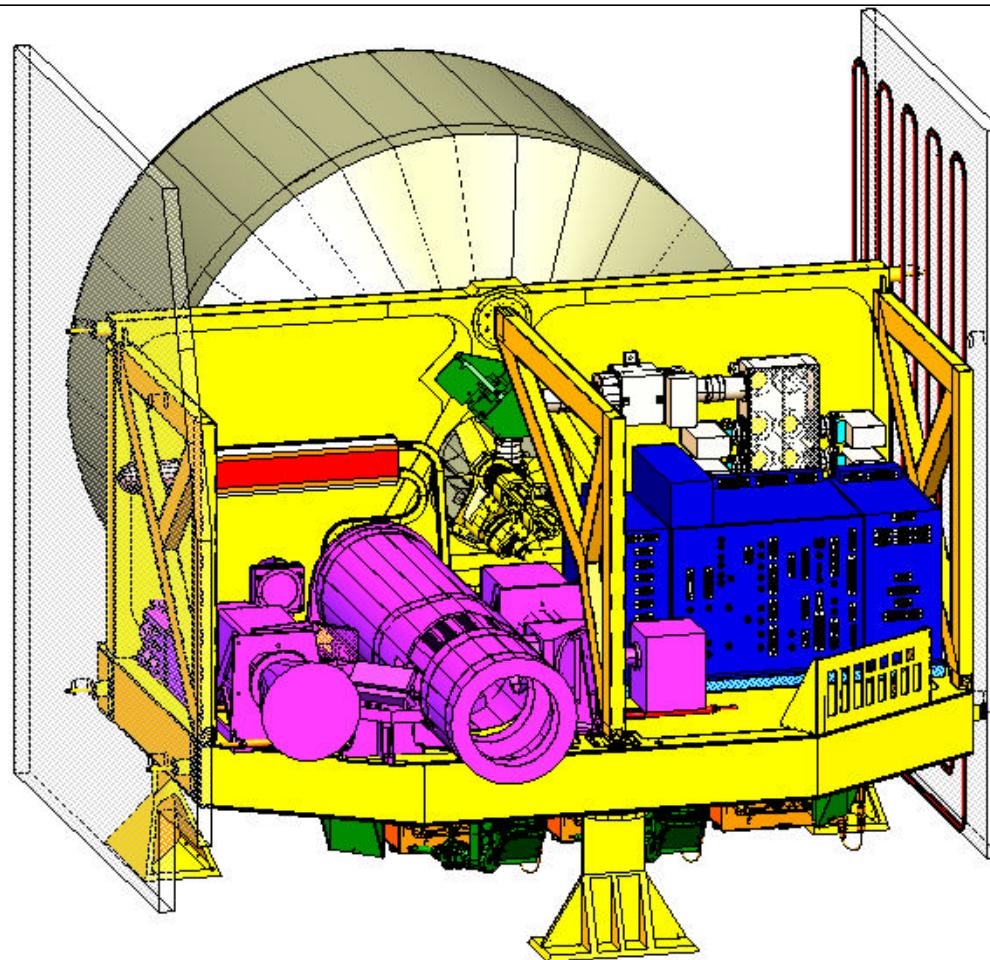
# Telescope STOP Analysis Summary

- The GLAS telescope design is athermal  
**Fabrication and mounting stresses not included in analysis**
- The GLAS telescope is very sensitive to primary mirror and secondary tower temperature gradients
- On-Orbit Cases:  
**Uniform primary mirror temperature on all cases**  
**Telescope axial gradient dominates blur circle**  
**Beta 90 is most worrisome on-orbit case**

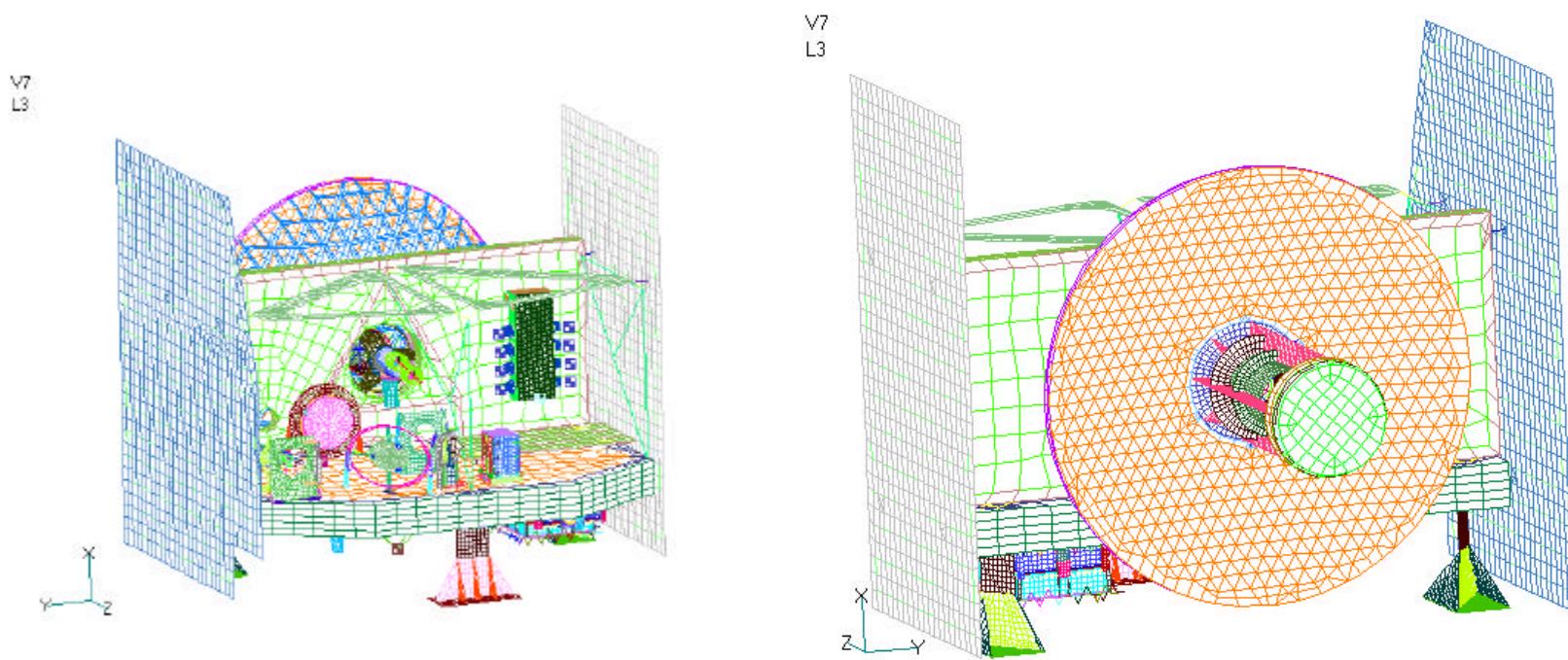
# GLAS Instrument STOP Analysis

- Instrument
  - Main Bench
    - 4" Honeycomb Aluminum Core, 0.08" Composite (M55J954-2A) face-sheet (34"X51")
    - CTE (ribbon) =  $0.21 \pm 0.01$  E-6 in/in/ $^{\circ}$ C (8"x8" sample)
    - CTE (X-ribbon) =  $0.08 \pm 0.01$  E-6 in/in/ $^{\circ}$ C
  - Mirror Bench
    - 2" Core and 0.06" face-sheet (22"x51")
    - CTE (ribbon) =  $0.31 \pm 0.01$  E-6 in/in/ $^{\circ}$ C (8"x8" sample)
    - CTE (X-ribbon) =  $0.00 \pm 0.01$  E-6 in/in/ $^{\circ}$ C
  - Tension Modulus, E=14.1E+6 psi
  - Conductivity, 24.2 W/m $^{\circ}$ K

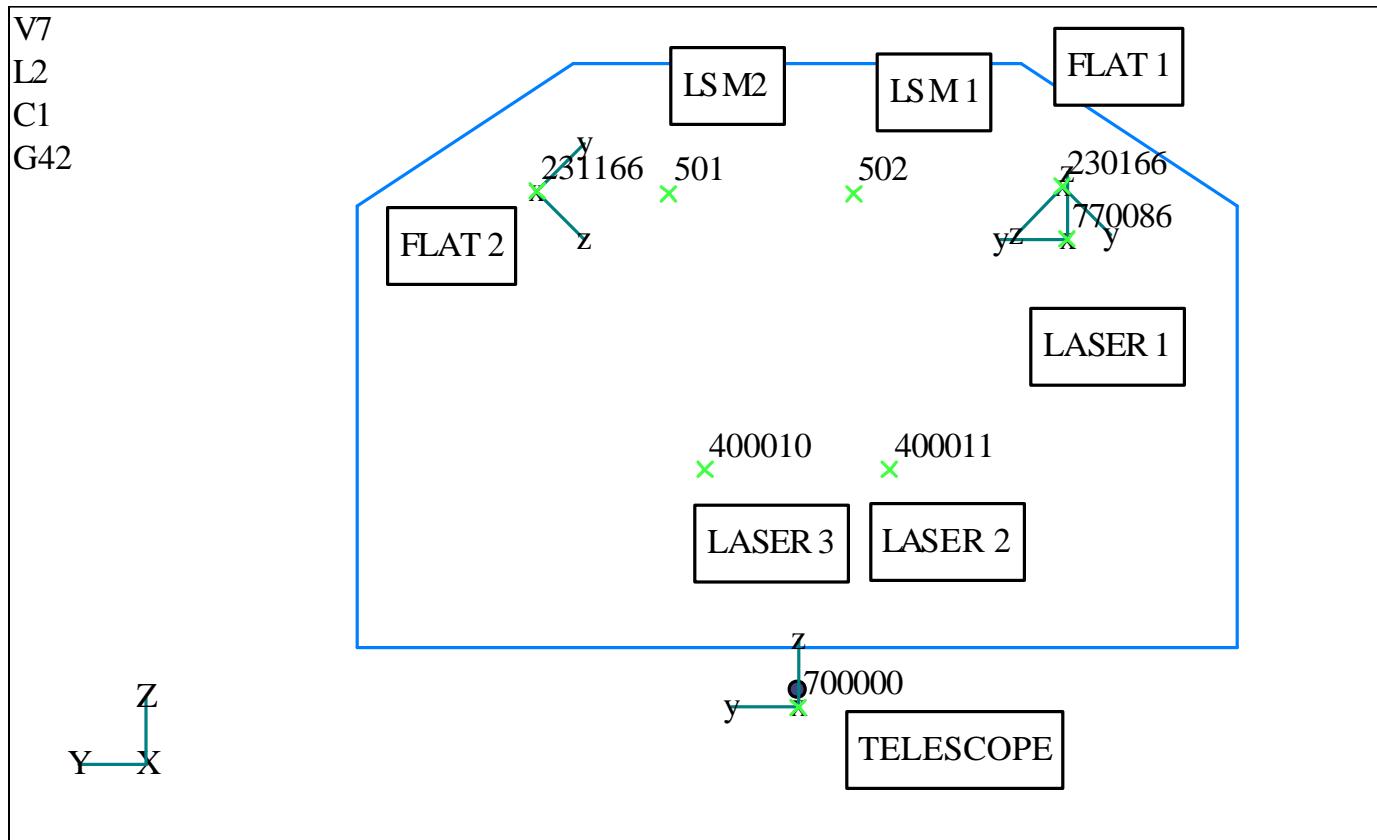
# GLAS Instrument



# GLAS FEM



# Instrument Optical Train



# Instrument Optical Train

The following equations predict the overall boresight error (laser relative to telescope) given the individual rotational error of the optical components:

$$\Delta\theta_x = \theta_{xL} - 2\theta_{xM1} + 2\theta_{xM2} - \theta_{xT}$$

$$\Delta\theta_y = -\theta_{yL} - 1.41\theta_{yM1} - 1.41\theta_{yM2} - \theta_{yT}$$

Where: L = laser, M1=flat1, M2=flat2, T=telescope

# Unit Gradient Along X- Axis

	X [in]	Y [in]	Z [in]	Rx [m- rads]	Ry [m-rads]	Rz [m- rads]	Rx [MPC/NASTRAN] [m- rads]
Laser 1	1.3745E-05	9.8143E-07	4.6468E-06	-0.1	-4.4	-0.1	
Laser 2	1.4890E-05	3.7407E-06	6.1536E-07	-0.1	1.0	-0.9	
Laser 3	1.8371E-05	4.7766E-06	-1.6495E-07	0.1	0.1	-0.6	
FLAT1	1.1785E-05	-2.1778E-06	5.5175E-07	-0.1	0.5	0.3	
LSM1	1.3800E-05	3.9046E-07	6.3970E-07	0.0	0.0	-0.1	
LSM2	1.3620E-05	-3.8286E-07	8.1199E-07	0.0	0.0	0.0	
FLAT2	1.1672E-05	1.6838E-06	-1.9378E-07	-0.1	0.0	-0.1	
Telescope	1.7534E-05	6.2424E-08	-6.9297E-05	0.1	3.3	0.0	
Laser1-Tel [Boresight Error]				-0.1	0.4		-0.1
Laser2-Tel [Boresight Error]				-0.2	-4.3		-0.2
Laser3-Tel [Boresight Error]				-0.2	-3.4		-0.2

# Unit Gradient Along Y- Axis

	X [in]	Y [in]	Z [in]	Rx [m- rads]	Ry [m-rads]	Rz [m- rads]	Rx [MPC/NASTRAN] [m- rads]
Laser 1	7.6717E-05	1.7381E-06	5.3715E-05	-0.3	1.6	0.0	
Laser 2	7.8140E-05	1.6534E-05	6.4615E-06	-0.5	5.1	-3.7	
Laser 3	8.6638E-05	1.9886E-05	4.6786E-06	0.2	2.6	-3.3	
FLAT1	9.4838E-05	-7.8061E-06	1.6958E-06	-0.7	0.7	2.4	
LSM1	1.0177E-04	1.5101E-06	8.8980E-06	-0.2	2.1	-0.4	
LSM2	1.0136E-04	2.4445E-07	8.8490E-06	0.1	2.1	-0.2	
FLAT2	9.2994E-05	5.3349E-06	-2.7283E-06	-0.4	-2.0	-1.5	
Telescope	5.8003E-05	-2.3015E-07	-9.4444E-05	0.1	2.3	0.0	
Laser1-Tel [Boresight Error]				0.3	-2.0		0.3
Laser2-Tel [Boresight Error]				-1.0	-7.5		-1.0
Laser3-Tel [Boresight Error]				-0.7	-5.0		-0.7

# Unit Gradient Along Z- Axis

	X [in]	Y [in]	Z [in]	Rx [m- rads]	Ry [m-rads]	Rz [m- rads]	Rx [MPC/NASTRAN] [m- rads]
Laser 1	1.9450E-05	1.8043E-05	1.2425E-05	3.0	0.1	-1.6	
Laser 2	4.8341E-05	9.8269E-06	3.4823E-06	-0.3	2.4	-4.0	
Laser 3	8.2957E-05	1.8530E-05	4.0057E-06	0.2	0.7	-4.9	
FLAT1	2.3079E-05	2.7820E-07	-1.2137E-06	0.0	1.9	1.7	
LSM1	5.0670E-05	1.8438E-06	3.3192E-06	0.1	0.1	-2.3	
LSM2	7.3321E-05	1.3758E-06	6.3756E-06	0.3	0.2	-2.2	
FLAT2	8.2364E-05	9.2908E-06	-3.0182E-06	-0.1	-2.0	1.3	
Telescope	6.9621E-05	-4.1985E-05	-7.2202E-05	-2.3	0.4	-2.8	
Laser1-Tel [Boresight Error]				5.2	-0.4		5.2
Laser2-Tel [Boresight Error]				1.6	-0.1		1.6
Laser3-Tel [Boresight Error]				1.6	1.5		1.6

# -20°C Bulk Temperature Change

	X [in]	Y [in]	Z [in]	Rx [m- rads]	Ry [m-rads]	Rz [m- rads]	Rx [MPC/NASTRAN] [m- rads]
Laser 1	-1.8516E-03	-2.7181E-05	-1.2891E-03	9.1	-3.3	-2.0	
Laser 2	-2.4330E-03	-4.0391E-04	-1.8285E-04	13.1	-105.0	91.8	
Laser 3	-2.7537E-03	-5.4377E-04	-1.1024E-04	-5.6	-18.3	84.1	
FLAT1	-2.1435E-03	2.3251E-04	1.9795E-05	17.5	-43.8	-24.9	
LSM1	-2.2964E-03	-3.1504E-05	-1.8196E-04	4.4	-6.5	8.4	
LSM2	-2.2957E-03	-1.0153E-05	-1.8235E-04	-2.5	-5.6	6.0	
FLAT2	-2.1220E-03	-1.6996E-04	1.1640E-04	7.1	19.8	2.7	
Telescope	-2.7874E-03	5.9980E-06	2.8833E-03	-3.8	-17.0	1.1	
Laser1-Tel [Boresight Error]				-7.9	54.1		-7.9
Laser2-Tel [Boresight Error]				22.3	103.1		22.3
Laser3-Tel [Boresight Error]				17.5	15.1		17.5

# Multi-Point Constraint (MPC) Equations

```
SPOINT,900011,900012,900021,900022,900031,900032
$ LASER1=770086, L2=400011, L3=400010, M1=230166, LSM1=502, LSM2=501, M2=231166,
$ TELESCOPE=700000
$ LASER 1 RX
$234567812345678123456781234567812345678123456781234567812345678
MPC      2 900011          -1.  770086      4     1.      +
+           230166      4    -2.  231166      4     2.      +
+           700000      4    -1.

$ LASER 1 RY
MPC      2 900012          -1.  770086      5    -1.      +
+           230166      5 -1.4142  231166      5 -1.4142      +
+           700000      5    -1.

$ LASER 2 RX
MPC      2 900021          -1.  400011      4     1.      +
+           502        4    -2.  231166      4     2.      +
+           700000      4    -1.

$ LASER 2 RY
MPC      2 900022          -1.  400011      5    -1.      +
+           502        5 -1.4142  231166      5 -1.4142      +
+           700000      5    -1.

$ LASER 3 RX
MPC      2 900031          -1.  400010      4     1.      +
+           501        4    -2.  231166      4     2.      +
+           700000      4    -1.

$ LASER 3 RY
MPC      2 900032          -1.  400010      5    -1.      +
+           501        5 -1.4142  231166      5 -1.4142      +
+           700000      5    -1.
```

# GLAS Instrument STOP Analysis

Remaining work:

- Add reduced laser models (laser 2 and 3) to the detail model.
- When available, map the latest on-orbit thermal cases onto GLAS FEM and determine boresite error for each laser.